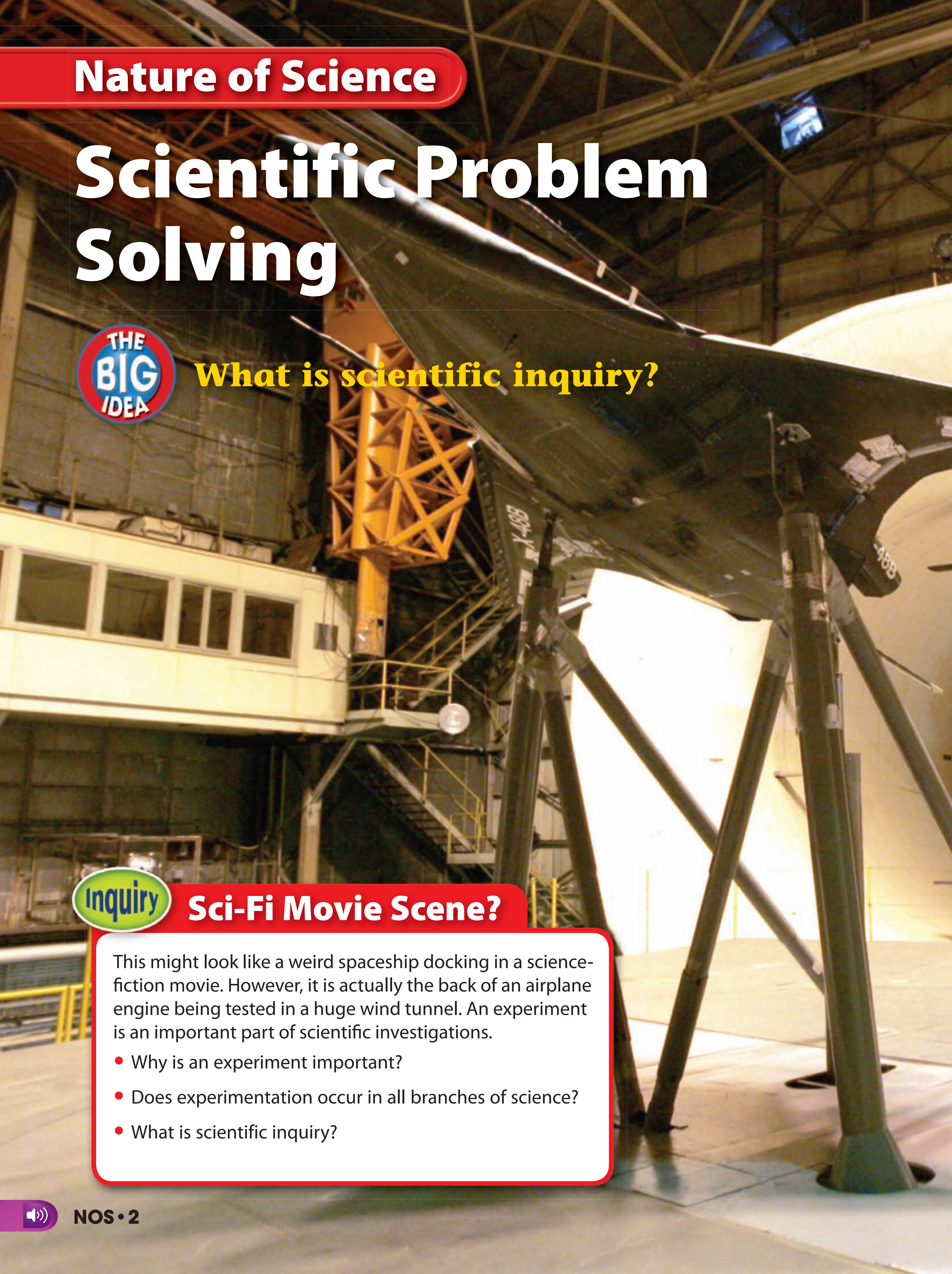
Scientific Problem Solving

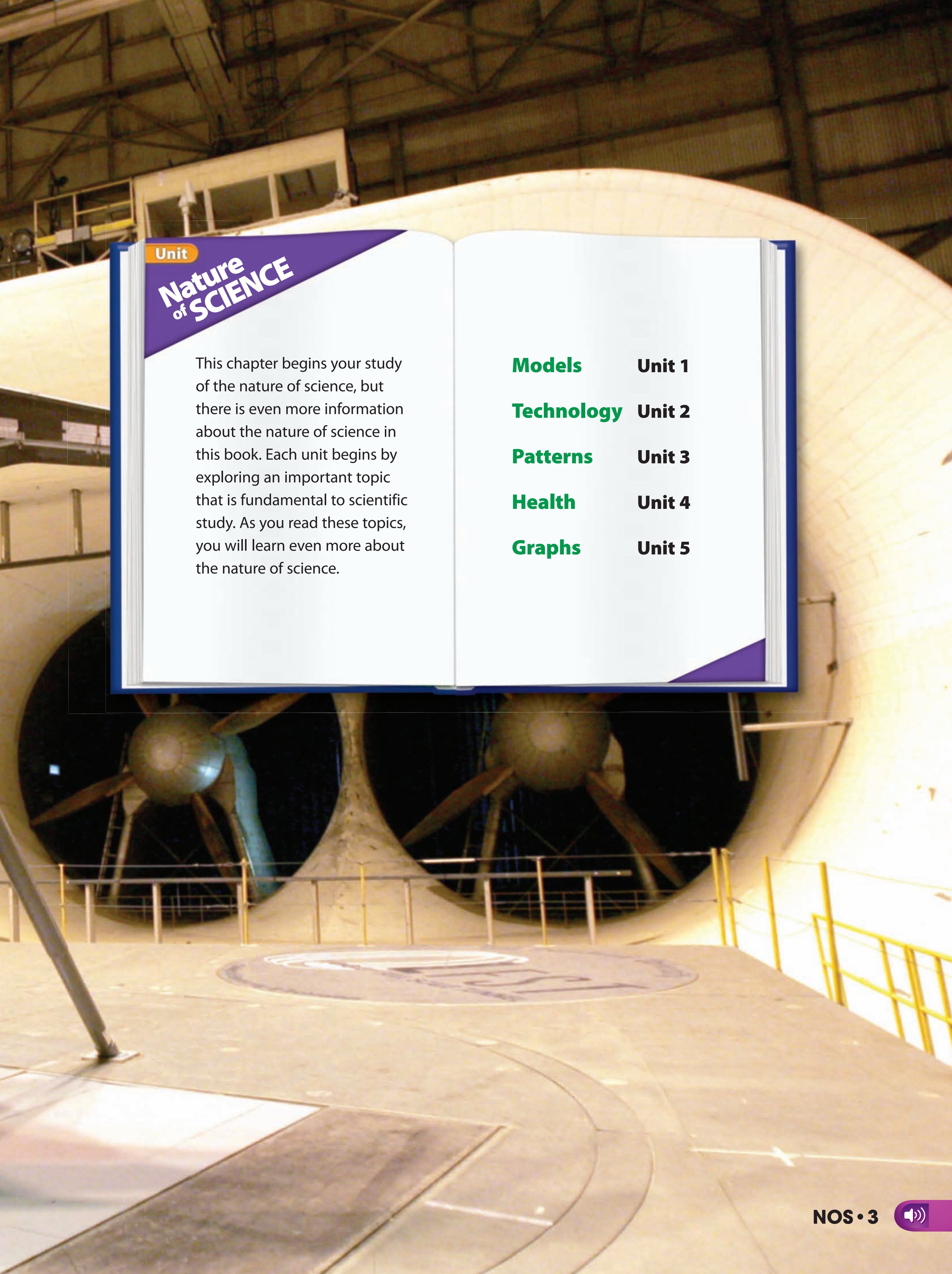


THE BIG IDEA **What is scientific inquiry?**

Inquiry Sci-Fi Movie Scene?

This might look like a weird spaceship docking in a science-fiction movie. However, it is actually the back of an airplane engine being tested in a huge wind tunnel. An experiment is an important part of scientific investigations.

- Why is an experiment important?
- Does experimentation occur in all branches of science?
- What is scientific inquiry?



Unit

Nature of SCIENCE

This chapter begins your study of the nature of science, but there is even more information about the nature of science in this book. Each unit begins by exploring an important topic that is fundamental to scientific study. As you read these topics, you will learn even more about the nature of science.

Lesson 1

Scientific Inquiry

Reading Guide

Key Concepts
ESSENTIAL QUESTIONS

- What are some steps used during scientific inquiry?
- What are the results of scientific inquiry?
- What is critical thinking?

Vocabulary

science p. NOS 4
observation p. NOS 6
inference p. NOS 6
hypothesis p. NOS 6
prediction p. NOS 6
scientific theory p. NOS 8
scientific law p. NOS 8
technology p. NOS 9
critical thinking p. NOS 10

Multilingual eGlossary

Video
- BrainPOP®
- Science Video

Understanding Science

A clear night sky is one of the most beautiful sights on Earth. The stars seem to shine like a handful of diamonds scattered on black velvet. Why do stars seem to shine more brightly some nights than others?

Did you know that when you ask questions, such as the one above, you are practicing science? **Science** *is the investigation and exploration of natural events and of the new information that results from those investigations.* Like a scientist, you can help shape the future by accumulating knowledge, developing new technologies, and sharing ideas with others.

Throughout history, people of many different backgrounds, interests, and talents have made scientific contributions. Sometimes they overcame a limited educational background and excelled in science. One example is Marie Curie, shown in **Figure 1.** She was a scientist who won two Nobel prizes in the early 1900s for her work with radioactivity. As a young student, Marie was not allowed to study at the University of Warsaw in Poland because she was a woman. Despite this obstacle, she made significant contributions to science.

Figure 1 Modern medical procedures such as X-rays, radioactive cancer treatments, and nuclear-power generation are some of the technologies made possible because of the pioneering work of Marie Curie and her associates.

Branches of Science

Scientific study is organized into several branches, or parts. The three branches that you will study in middle school are physical science, Earth science, and life science. Each branch focuses on a different part of the natural world.

Word Origin

science
from Latin *scientia,* means "knowledge" or "to know"

Physical Science

Physical science, or physics and chemistry, is the study of matter and energy. The physicist shown here is adjusting an instrument that measures radiation from the Big Bang. Physical scientists ask questions such as

- What happens to energy during chemical reactions?
- How does gravity affect roller coasters?
- What makes up protons, neutrons, and electrons?

Earth Science

Earth scientists study the many processes that occur on Earth and deep within Earth. This scientist is collecting a water sample in southern Mexico.

Earth scientists ask questions such as

- What are the properties of minerals?
- How is energy transferred on Earth?
- How do volcanoes form?

Life Science

Life scientists study all organisms and the many processes that occur in them. The life scientist shown is studying the avian flu virus.

Life scientists ask questions such as

- How do plant cells and animal cells differ?
- How do animals survive in the desert?
- How do organisms in a community interact?

What is Scientific Inquiry?

When scientists conduct investigations, they often want to answer questions about the natural world. To do this, they use scientific inquiry—a process that uses a variety of skills and tools to answer questions or to test ideas. You might have heard these steps called "the scientific method." However, there is no one scientific method. In fact, the skills that scientists use to conduct an investigation can be used in any order. One possible sequence is shown in **Figure 2.** Like a scientist, you perform scientific investigations every day, and you will do investigations throughout this course.

Reading Check What is scientific inquiry?

Ask Questions

Imagine warming yourself near a fireplace or a campfire? As you throw twigs and logs onto the fire, you see that fire releases smoke and light. You also feel the warmth of the thermal energy being released. These are **observations**—*the results of using one or more of your senses to gather information and taking note of what occurs.* Observations often lead to questions. You ask yourself, "When logs burn, what happens to the wood? Do the logs disappear? Do they change in some way?"

When observing the fire, you might recall from an earlier science course that matter can change form, but it cannot be created or destroyed. Therefore, you infer that the logs do not just disappear. They must undergo some type of change. An **inference** *is a logical explanation of an observation that is drawn from prior knowledge or experience.*

Hypothesize and Predict

After making observations and inferences, you decide to investigate further. Like a scientist, you might develop a **hypothesis**—*a possible explanation for an observation that can be tested by scientific investigations.* Your hypothesis about what happens to the logs might be: When logs burn, new substances form because matter cannot be destroyed.

When scientists state a hypothesis, they often use it to make predictions to help test their hypothesis. *A* **prediction** *is a statement of what will happen next in a sequence of events.* Scientists make predictions based on what information they think they will find when testing their hypothesis. For instance, based on your hypothesis, you might predict that if logs burn, then the substances that make up the logs change into other substances.

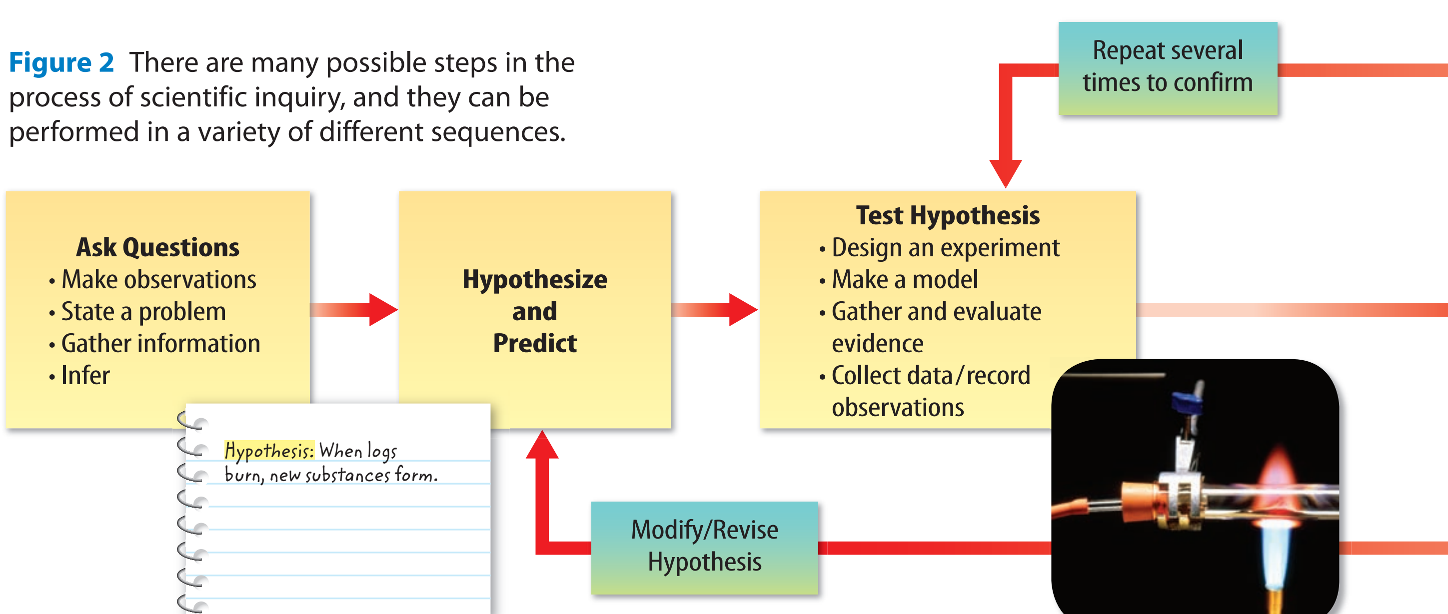


Figure 2 There are many possible steps in the process of scientific inquiry, and they can be performed in a variety of different sequences.

Test Hypothesis and Analyze Results

How could you test your hypothesis? When you test a hypothesis, you often test your predictions. If a prediction is confirmed, then it supports your hypothesis. If your prediction is not confirmed, you might modify your hypothesis and retest it.

To test your predictions and hypothesis, you could design an experiment to find out what substances make up wood. Then you could determine what makes up the ash, the smoke, and other products that formed after the burning process. You also could research this topic and possibly find answers on reliable science Web sites or in science books.

After doing an experiment or research, you need to analyze your results and findings. You might make additional inferences after reviewing your data. If you find that new substances actually do form when wood burns, your hypothesis is supported. If new products do not form, your hypothesis is not supported. Some methods of testing a hypothesis and analyzing results are shown in **Figure 2.**

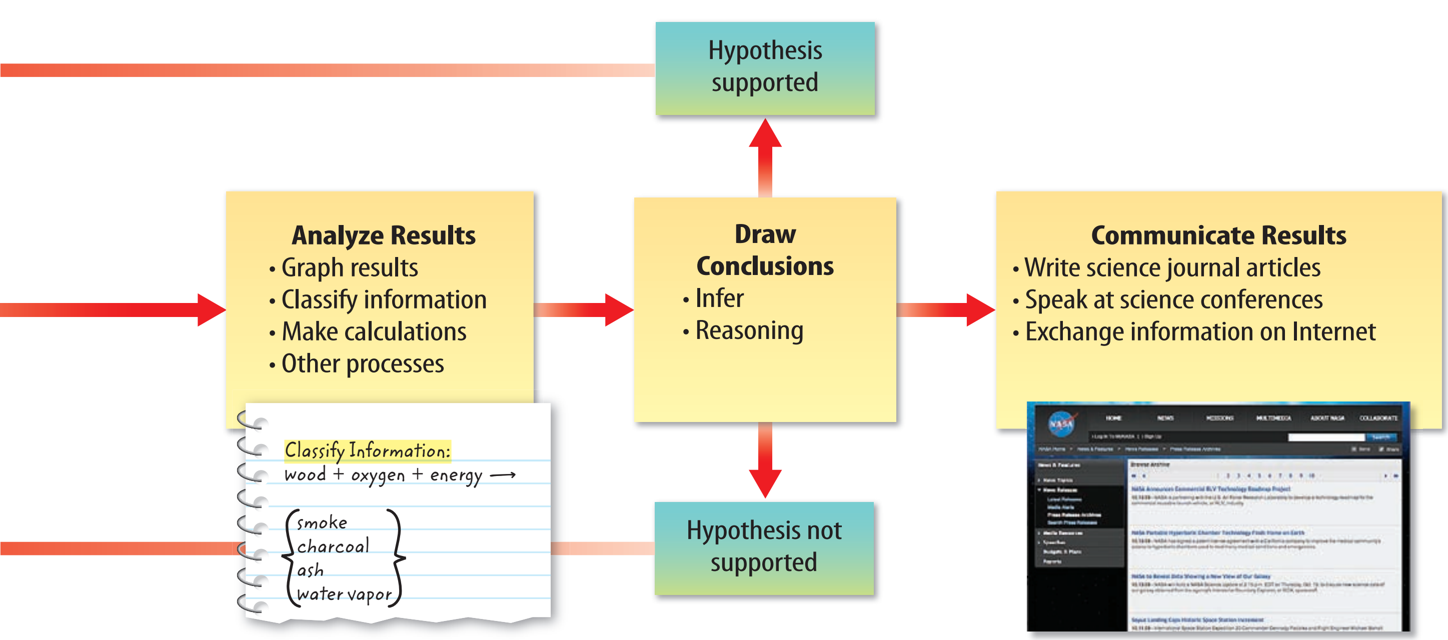
Draw Conclusions

After analyzing your results, you can begin to draw conclusions about your investigation. A conclusion is a summary of the information gained from testing a hypothesis. Like a scientist does, you should test and retest your hypothesis several times to make sure the results are consistent.

Communicate Results

Sharing the results of a scientific inquiry is an important part of science. By exchanging information, scientists can evaluate and test others' work and make faster progress in their own research. Exchanging information is one way of making scientific advances as quickly as possible and keeping scientific information accurate. During your investigation, if you do research on the Internet or in science books, you use information that someone else communicated. Scientists exchange information in many ways, as shown below in **Figure 2.**

Key Concept Check What are some steps used during scientific inquiry?



Unsupported or Supported Hypotheses

What happens if a hypothesis is not supported by an investigation? Was the scientific investigation a failure and a waste of time? Absolutely not! Even when a hypothesis is not supported, you gain valuable information. You can revise your hypothesis and test it again. Each time you test a hypothesis, you learn more about the topic you are studying.

Scientific Theory

When a hypothesis (or a group of closely related hypotheses) is supported through many tests over many years, a scientific theory can develop. A **scientific theory** *is an explanation of observations or events that is based on knowledge gained from many observations and investigations.*

A scientific theory does not develop from just one hypothesis, but from many hypotheses that are connected by a common idea. The kinetic molecular theory described below is the result of the investigations of many scientists.

Scientific Law

A scientific law is different from a societal law, which is an agreement on a set of behaviors. A **scientific law** *is a rule that describes a repeatable pattern in nature.* A scientific law does not explain why or how the pattern happens, it only states that it will happen. For example, if you drop a ball, it will fall towards the ground every time. This is a repeated pattern that relates to the law of universal gravitation. The law of conservation of energy, described below, is also a scientific law.

Kinetic Molecular Theory

The kinetic molecular theory explains how particles that make up a gas move in constant, random motions. A particle moves in a straight line until it collides with another particle or with the wall of its container.

The kinetic molecular theory also assumes that the collisions of particles in a gas are elastic collisions. An elastic collision is a collision in which no kinetic energy is lost. Therefore, kinetic energy among gas particles is conserved.

Law of Conservation of Energy

The law of conservation of energy states that in any chemical reaction or physical change, energy is neither created nor destroyed. The total energy of particles before and after collisions is the same.

However, this scientific law, like all scientific laws, does not explain *why* energy is conserved. It simply states that energy *is* conserved.

Scientific Law v. Scientific Theory

Both are based on repeated observations and can be rejected or modified.

A scientific law states that an event *will* occur. For example, energy will be conserved when particles collide. It does not explain why an event will occur or how it will occur. Scientific laws work under specific conditions in nature. A law stands true until an observation is made that does not follow the law.

A scientific theory is an explanation of *why* or *how* an event occurred. For example, collisions of particles of a gas are elastic collisions. Therefore, no kinetic energy is lost. A theory can be rejected or modified if someone observes an event that disproves the theory. A theory will never become a law.

Results of Scientific Inquiry

Why do you and others ask questions and investigate the natural world? Just as scientific questions vary, so do the results of science. Most often, the purpose of a scientific investigation is to develop new materials and technology, discover new objects, or find answers to questions, as shown below.

Key Concept Check What are the results of scientific inquiry?

New Materials and Technology

Every year, corporations and governments spend millions of dollars on research and design of new materials and technologies. **Technology** *is the practical use of scientific knowledge, especially for industrial or commercial use.* For example, scientists hypothesize and predict how new materials will make bicycles and cycling gear lighter, more durable, and more aerodynamic. Using wind tunnels, scientists test these new materials to see whether they improve the cyclist's performance. If the cyclist's performance improves, their hypotheses are supported. If the performance does not improve or it doesn't improve enough, scientists will revise their hypotheses and conduct more tests.

New Objects or Events

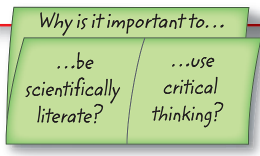
Scientific investigations also lead to newly discovered objects or events. For example, NASA's *Hubble Space Telescope* captured this image of two colliding galaxies. They have been nicknamed the mice, because of their long tails. The tails are composed of gases and young, hot blue stars. If computer models are correct, these galaxies will combine in the future and form one large galaxy.

Answers to Questions

Often scientific investigations are launched to answer *who, what, when, where,* or *how* questions. For example, research chemists investigate new substances, such as substances found in mushrooms and bacteria, as shown on the right. New drug treatments for cancer, HIV, and other diseases might be found using new substances. Other scientists look for clues about what causes diseases, whether they can be passed from person to person, and when the disease first appeared.

FOLDABLES®

Create a two-tab book and label it as shown. Use it to discuss the importance of evaluating scientific information.



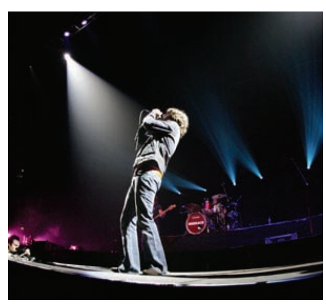
Evaluating Scientific Information

Do you ever you read advertisements, articles, or books that claim to contain scientifically proven information? Are you able to determine if the information is actually true and scientific instead of pseudoscientific (information incorrectly represented as scientific)? Whether you are reading printed media or watching commercials on TV, it is important that you are skeptical, identify facts and opinions, and think critically about the information. **Critical thinking** *is comparing what you already know with the information you are given in order to decide whether you agree with it.*

Key Concept Check What is critical thinking?

Be A Rock Star!

Do you dream of being a rock star?



Sing, dance, and play guitar like a rock star with the new Rocker-rific Spotlight. A new scientific process developed by Rising Star Laboratories allows you to overcome your lack of musical talent and enables you to perform like a real rock star.

This amazing new light actually changes your voice quality and enhances your brain chemistry so that you can sing, dance, and play a guitar like a professional rock star. Now, there is no need to practice or pay for expensive lessons. The Rocker-rific Spotlight does the work for you.

Dr. Sammy Truelove says, "Before lack of talent might have stopped someone from achieving his or her dreams of being a rock star. This scientific breakthrough transforms people with absolutely no talent into amazing rock stars in just minutes. Of the many patients that I have tested with this product, no one has failed to achieve his or her dreams."

Disclaimer: This product was tested on laboratory rats and might not work for everyone.

Skepticism
Have you heard the saying, if it sounds too good to be true, it probably is? To be skeptical is to doubt the truthfulness of something. A scientifically literate person can read information and know that it misrepresents the facts. Science often is self-correcting because someone usually challenges inaccurate information and tests scientific results for accuracy.

Identifying Facts and Misleading Information
Misleading information often is worded to sound like scientific facts. A scientifically literate person can recognize fake claims and quickly determine when information is false.

Critical Thinking
Use critical thinking skills to compare what you know with the new information given to you. If the information does not sound reliable, either research and find more information about the topic or dismiss the information as unreliable.

Identify Opinions
An opinion is a personal view, feeling, or claim about a topic. Opinions cannot be proven true or false. And, an opinion might contain inaccurate information.

Science cannot answer all questions.

It might seem that scientific inquiry is the best way to answer all questions. But there are some questions that science cannot answer. Questions that deal with beliefs, values, personal opinions, and feelings cannot be answered scientifically. This is because it is impossible to collect scientific data on these topics.

Science cannot answer questions such as

- Which video game is the most fun to play?
- Are people kind to others most of the time?
- Is there such a thing as good luck?

Safety in Science

Scientists know that using safe procedures is important in any scientific investigation. When you begin a scientific investigation, you should always wear protective equipment, as shown in **Figure 3.** You also should learn the meaning of safety symbols, listen to your teacher's instructions, and learn to recognize potential hazards. For more information, consult the Science Skills Handbook at the back of this book.

Figure 3 Always follow safety procedures when doing scientific investigations. If you have questions, ask your teacher.

Assessment Online Quiz

Inquiry Virtual Lab

Lesson 1 Review

Use Vocabulary

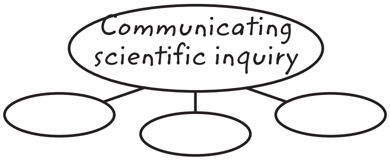
1. **Define** *technology* in your own words.
2. **Use the term** *observation* in a sentence.

Understand Key Concepts

3. Which action is NOT a way to test a hypothesis?
   A. analyze results
   B. design an experiment
   C. make a model
   D. gather and evaluate evidence
4. **Describe** three examples of the results of scientific inquiry.
5. **Give an example** of a time when you practiced critical thinking.

Interpret Graphics

6. **Compare** Copy and fill in the graphic organizer below. List some examples of how to communicate the results of scientific inquiry.



Critical Thinking

7. **Summarize** Your classmate writes the following as a hypothesis:

   Red is a beautiful color.

   Write a brief explanation to your classmate explaining why this is not a hypothesis.

Lesson 2

Measurement and Scientific Tools

Reading Guide

Key Concepts

ESSENTIAL QUESTIONS

- Why did scientists create the International System of Units (SI)?
- Why is scientific notation a useful tool for scientists?
- How can tools, such as graduated cylinders and triple-beam balances, assist physical scientists?

Vocabulary

description p. NOS 12
explanation p. NOS 12
International System of Units (SI) p. NOS 12
scientific notation p. NOS 15
percent error p. NOS 15

g Multilingual eGlossary

Description and Explanation

Suppose you work for a company that tests cars to see how they perform during accidents, as shown in **Figure 4.** You might use various scientific tools to measure the acceleration of cars as they crash into other objects.

A **description** *is a spoken or written summary of observations.* The measurements you record are descriptions of the results of the crash tests. Later, your supervisor asks you to write a report that interprets the measurements you took during the crash tests. An **explanation** *is an interpretation of observations.* As you write your explanation, you make inferences about why the crashes damaged the vehicles in specific ways.

Notice that there is a difference between a description and an explanation. When you describe something, you report your observations. When you explain something, you interpret your observations.

The International System of Units

Different parts of the world use different systems of measurements. This can cause confusion when people who use different systems communicate their measurements. This confusion was eliminated in 1960 when a new system of measurement was adopted. *The internationally accepted system of measurement is the* **International System of Units (SI).**

Key Concept Check Why did scientists create the International System of Units?

Figure 4 A description of an event details what you observed. An explanation explains why or how the event occurred.

SI Base Units

When you take measurements during scientific investigations and labs in this course, you will use the SI system. The SI system uses standards of measurement, called base units, as shown in **Table 1.** Other units used in the SI system that are not base units are derived from the base units. For example, the liter, used to measure volume, was derived from the base unit for length.

SI Unit Prefixes

In older systems of measurement, there usually was no common factor that related one unit to another. The SI system eliminated this problem.

The SI system is based on multiples of ten. Any SI unit can be converted to another by multiplying by a power of ten. Factors of ten are represented by prefixes, as shown in **Table 2.** For example, the prefix *milli-* means 0.001 or 10^{-3}. So, a milliliter is 0.001 L, or 1/1,000 L. Another way to say this is: 1 L is 1,000 times greater than 1 mL.

Converting Among SI Units

It is easy to convert from one SI unit to another. You either multiply or divide by a factor of ten. You also can use proportion calculations to make conversions. An example of how to convert between SI units is shown in **Figure 5.**

Concepts in Motion Interactive Table

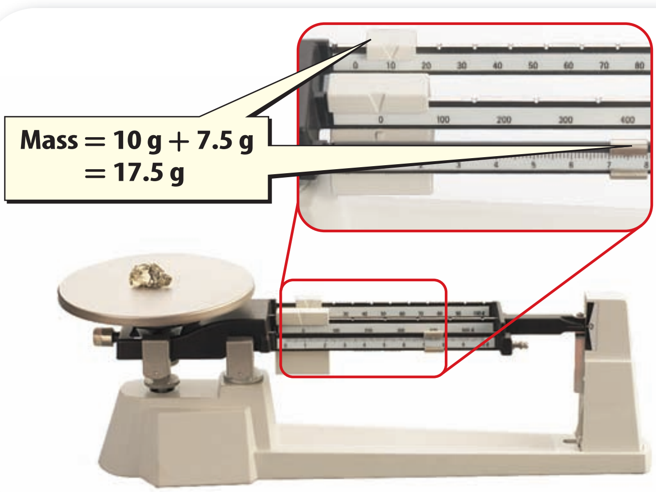
Table 1 SI Base Units

Quantity Measured	Unit (symbol)
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Electric current	ampere (A)
Temperature	kelvin (K)
Substance amount	mole (mol)
Light intensity	candela (cd)

Table 2 Prefixes

Prefix	Meaning
Mega- (M)	1,000,000 or (10^6)
Kilo- (k)	1,000 or (10^3)
Hecto- (h)	100 or (10^2)
Deka- (da)	10 or (10^1)
Deci- (d)	0.1 or $\left(\frac{1}{10}\right)$ or (10^{-1})
Centi- (c)	0.01 or $\left(\frac{1}{100}\right)$ or (10^{-2})
Milli- (m)	0.001 or $\left(\frac{1}{1{,}000}\right)$ or (10^{-3})
Micro- (μ)	0.000001 or $\left(\frac{1}{1{,}000{,}000}\right)$ or (10^{-6})

Figure 5 The rock in the photograph has a mass of 17.5 grams. Convert that measurement to kilograms.



1. Determine the correct relationship between grams and kilograms. There are 1,000 g in 1 kg.

$$\frac{1\text{ kg}}{1{,}000\text{ g}}$$

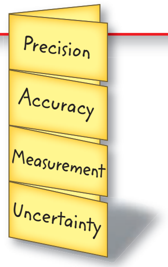
$$\frac{x}{17.5\text{ g}} = \frac{1\text{ kg}}{1{,}000\text{ g}}$$

$$x = \frac{(17.5\text{ }\cancel{g})(1\text{ kg})}{1{,}000\text{ }\cancel{g}};\ x = 0.0175\text{ kg}$$

2. Check your units. The unit *grams* is cancelled out in the equation, so the answer is 0.0175 kg.

FOLDABLES®

Make a four-tab book and label it as shown. Use it to organize your notes on scientific measurement.



WORD ORIGIN

notation
from Latin *notationem,* means "a marking or explanation"

Table 3 Student Density and Error Data
(Accepted value: Density of sodium chloride, 21.7 g/cm³)

	Student A	Student B	Student C
	Density	Density	Density
Trial 1	23.4 g/cm³	18.9 g/cm³	21.9 g/cm³
Trial 2	23.5 g/cm³	27.2 g/cm³	21.4 g/cm³
Trial 3	23.4 g/cm³	29.1 g/cm³	21.3 g/cm³
Mean	23.4 g/cm³	25.1 g/cm³	21.5 g/cm³

Measurement and Uncertainty

You might be familiar with the terms *precision* and *accuracy*. In science, these terms have different meanings. Precision is a description of how similar or close repeated measurements are to each other. Accuracy is a description of how close a measurement is to an accepted value.

The difference between precision and accuracy is illustrated in **Table 3.** Students were asked to find the density of sodium chloride (NaCl). In three trials, each student measured the volume and the mass of NaCl. Then, they calculated the density for each trial and calculated the mean, or average. Student A's measurements are the most precise because they are closest to each other. Student C's measurements are the most accurate because they are closest to the scientifically accepted value. Student B's measurements are neither precise nor accurate. They are not close to each other or to the accepted value.

Tools and Accuracy

No measuring tool provides a perfect measurement. All measurements have some degree of uncertainty. Some tools or instruments produce more accurate measurements, as shown in **Figure 6.**

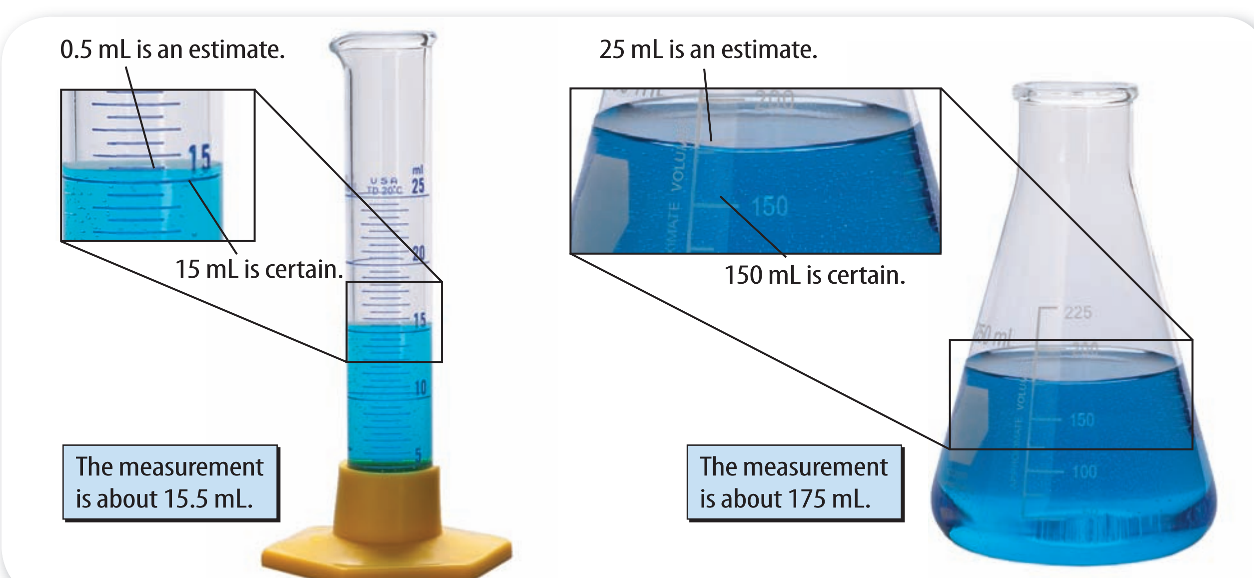


Figure 6 The graduated cylinder is graduated in 1-mL increments. The beaker is graduated in, or divided into, 50-mL increments. Liquid measurements taken with the graduated cylinder have greater accuracy.

Scientific Notation

Suppose you are writing a report that includes Earth's distance from the Sun—149,600,000 km—and the density of the Sun's lower atmosphere—0.000000028 g/cm^3. These numerals take up too much space and might be difficult to read, so you use **scientific notation**—*a method of writing or displaying very small or very large values in a short form*. To write the numerals in scientific notation, use the steps shown to the right.

Key Concept Check Why is scientific notation a useful tool for scientists?

Percent Error

The densities recorded in **Table 3** are experimental values because they were calculated during an experiment. Each of these values has some error because the accepted value for table salt density is 21.65 g/cm^3. Percent error can help you determine the size of your experimental error. **Percent error** *is the expression of error as a percentage of the accepted value.*

How to Write in Scientific Notation

1. Write the original number.
   - **A.** **149,600,000**
   - **B.** **0.000000028**
2. Move the decimal point to the right or the left to make the number between 1 and 10. Count the number of decimal places moved and note the direction.
   - **A.** **1.49600000** = 8 places to the left
   - **B.** **00000002.8** = 8 places to the right
3. Rewrite the number deleting all extra zeros to the right or to the left of the decimal point.
   - **A.** **1.496**
   - **B.** **2.8**
4. Write a multiplication symbol and the number *10* with an exponent. The exponent should equal the number of places that you moved the decimal point in step 2. If you moved the decimal point to the left, the exponent is positive. If you moved the decimal point to the right, the exponent is negative.
   - **A.** **1.496×10^8**
   - **B.** **2.8×10^{-8}**

Math Skills — Percent Error

Solve for Percent Error A student in the laboratory measures the boiling point of water at 97.5°C. If the accepted value for the boiling point of water is 100.0°C, what is the percent error?

1. This is what you know: **experimental value** = **97.5°C**; **accepted value** = **100.0°C**
2. This is what you need to find: percent error
3. Use this formula:

$$\text{percent error} = \frac{|\text{experimental value} - \text{accepted value}|}{\text{accepted value}} \times 100\%$$

4. Substitute the known values into the equation and perform the calculations

$$\text{percent error} = \frac{|97.5° - 100.0°|}{100.0°} \times 100\% = 2.50\%$$

Practice

Calculate the percent error if the experimental value of the density of gold is 18.7 g/cm^3 and the accepted value is 19.3 g/cm^3.

Review
- Math Practice
- Personal Tutor

Scientific Tools

As you conduct scientific investigations, you will use tools to make measurements. The tools listed here are some of the tools commonly used in science. For more information about the correct use and safety procedures for these tools, see the Science Skills Handbook at the back of this book.

◀ Science Journal

Use a science journal to record observations, write questions and hypotheses, collect data, and analyze the results of scientific inquiry. All scientists record the information they learn while conducting investigations. Your journal can be a spiral-bound notebook, a loose-leaf binder, or even just a pad of paper.

Balances ▶

A balance is used to measure the mass of an object. Units often used for mass are kilograms (kg), grams (g), and milligrams (mg). Two common types of balances are the electronic balance and the triple-beam balance. In order to get the most accurate measurements when using a balance, it is important to calibrate the balance often.

◀ Glassware

Laboratory glassware is used to hold or measure the volume of liquids. Flasks, beakers, test tubes, and graduated cylinders are just some of the different types of glassware available. Volume usually is measured in liters (L) and milliliters (mL).

Thermometers ▶

A thermometer is used to measure the temperature of substances. Although Kelvin is the SI unit of measurement for temperature, in the science classroom, you often measure temperature in degrees Celsius (°C). Never stir a substance with a thermometer because it might break. If a thermometer does break, tell your teacher immediately. Do not touch the broken glass or the liquid inside the thermometer.

◀ Calculators

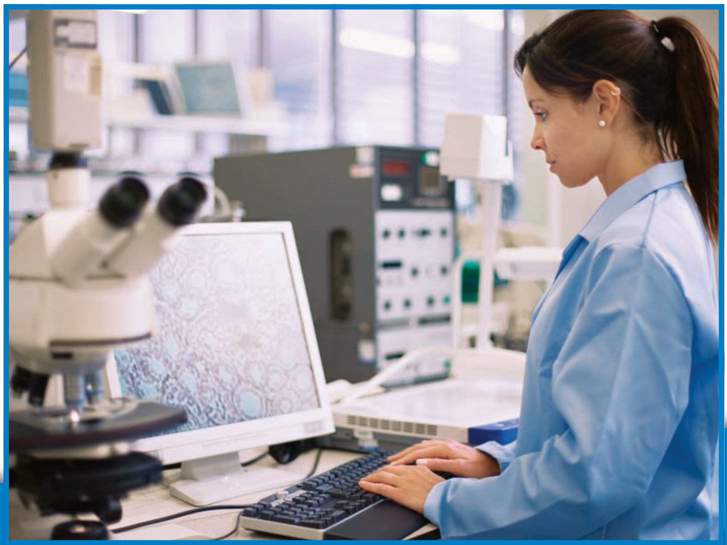
A hand-held calculator is a scientific tool that you might use in math class. But you also can use it in the lab and in the field (real situation outside the lab) to make quick calculations using your data.

Computers ▼

For today's students, it is difficult to think of a time when scientists—or anyone—did not use computers in their work. Scientists can collect, compile, and analyze data more quickly using a computer. Scientists use computers to prepare research reports and to share their data and ideas with investigators worldwide.

Hardware refers to the physical components of a computer, such as the monitor and the mouse. Computer software refers to the programs that are run on computers, such as word processing, spreadsheet, and presentation programs.

Electronic probes can be attached to computers and handheld calculators to record measurements. There are probes for collecting different kinds of information, such as temperature and the speed of objects.



Key Concept Check How can scientific tools, such as graduated cylinders and triple-beam balances, assist scientists?

Additional Tools Used by Physical Scientists

You can use pH paper to quickly estimate the acidity of a liquid substance. The paper changes color when it comes into contact with an acid or a base.

Scientists use stopwatches to measure the time it takes for an event to occur. The SI unit for time is seconds (s). However, for longer events, the units *minutes (min)* and *hours (h)* can be used.

A hot plate is a small heating device that can be placed on a table or desk. Hot plates are used to heat substances in the laboratory.

You use a spring scale to measure the weight or the amount of force applied to an object. The SI unit for weight is the newton (N).

Lesson 2 Review

Assessment Online Quiz

Use Vocabulary

1. A spoken or written summary of observations is a(n) __________, while a(n) __________ is an interpretation of observations.

Understand Key Concepts

2. Which type of glassware would you use to measure the volume of a liquid?
   A. beaker
   B. flask
   C. graduated cylinder
   D. test tube

3. **Summarize** why a scientist measuring the diameter of an atom or the distance to the Moon would use scientific notation.

4. **Explain** why scientists use the International System of Units (SI).

Interpret Graphics

5. **Identify** Copy and fill in the graphic organizer below listing some scientific tools that you could use to collect data.

Critical Thinking

6. **Explain** why precision and accuracy should be reported in a scientific investigation.

Math Skills

Review
Math Practice

7. Calculate the percent error if the experimental value for the density of zinc is 9.95 g/cm^3. The accepted value is 7.13 g/cm^3.

How do geometric shapes differ in strength?

Materials

plastic straws

scissors

ruler

string

Safety

If you look at a bridge, a building crane, or the framework of a tall building, you will notice that various geometric shapes make up the structure. In this activity, you will observe the strength of several geometric shapes in terms of their rigidity, or resistance to changing their shape.

Learn It

When scientists make a hypothesis, they often then **predict** that an event will occur based on their hypothesis.

Try It

1. Read and complete a lab safety form.
2. You are going to construct a triangle and a square using straws. Predict which shape will be more resistant to changing shape and write your prediction in your Science Journal.
3. Measure and cut the straws into seven segments, each 6 cm long.
4. Measure and cut one 20-cm and one 30-cm length of string.
5. Thread the 30-cm length of string through four straw segments. Bend the corners to form a square. Tie the ends of the string together in a double knot to complete the square.
6. Thread the 20-cm string through three of the straw segments. Bend to form a triangle. Tie the ends of the string together to complete the triangle.
7. Test the strength of the square by gently trying to change its shape. Repeat with the triangle. Record your observations.
8. Propose several ways to make the weaker shape stronger. Draw diagrams showing how to modify the shape to make it more rigid.
9. Test your hypothesis. If necessary, refine your hypothesis and retest it. Repeat this step until you make the shape stronger.

Apply It

10. Look at the photograph at to the left. Which of your tested shapes is used the most? Based on your observations, why is this shape used?
11. What modifications made your shape stronger? Why?
12. **Key Concept** How might a scientist use a model to test a hypothesis?

Lesson 3

Reading Guide

Key Concepts
ESSENTIAL QUESTIONS

- Why are evaluation and testing important in the design process?
- How is scientific inquiry used in a real-life scientific investigation?

Vocabulary

variable p. NOS 21
constant p. NOS 21
independent variable p. NOS 21
dependent variable p. NOS 21
experimental group p. NOS 21
control group p. NOS 21
qualitative data p. NOS 24
quantitative data p. NOS 24

Multilingual eGlossary

Video Science Video

Case Study

The Minneapolis Bridge Failure

On August 1, 2007, the center section of the Interstate-35W (I-35W) bridge in Minneapolis, Minnesota, suddenly collapsed. A major portion of the bridge fell more than 30 m into the Mississippi River, as shown in **Figure 7.** There were more than 100 cars and trucks on the bridge at the time, including a school bus carrying over 50 students.

The failure of this 8-lane, 581-m long interstate bridge came as a surprise to almost everyone. Drivers do not expect a bridge to drop out from underneath them. The design and engineering processes that bridges undergo are supposed to ensure that bridge failures do not happen.

Controlled Experiments

After the 2007 bridge collapse, investigators had to determine why the bridge failed. To do this, they needed to use scientific inquiry, which you read about in Lesson 1. The investigators designed controlled experiments to help them answer questions and test their hypotheses. A controlled experiment is a scientific investigation that tests how one factor affects another. You might conduct controlled experiments to help discover answers to questions, to test a hypotheses, or to collect data.

Figure 7 A portion of the Interstate-35W bridge in Minneapolis, Minnesota, collapsed in August 2007. Several people were killed, and many more were injured.

Identifying Variables and Constants

When conducting an experiment, you must identify factors that can affect the experiment's outcome. A **variable** *is any factor that can have more than one value.* In controlled experiments, there are two kinds of variables. The **independent variable** *is the factor that you want to test. It is changed by the investigator to observe how it affects a dependent variable.* The **dependent variable** *is the factor you observe or measure during an experiment.* **Constants** *are the factors in an experiment that do not change.*

Experimental Groups

A controlled experiment usually has at least two groups. The **experimental group** *is used to study how a change in the independent variable changes the dependent variable.* The **control group** *contains the same factors as the experimental group, but the independent variable is not changed.* Without a control, it is impossible to know whether your experimental observations result from the variable you are testing or some other factor.

This case study will explore how the investigators used scientific inquiry to determine why the bridge collapsed. Notebooks in the margin identify what a scientist might write in a science journal. The blue boxes contain additional helpful information that you might use.

You can change the independent variable to observe how it affects the dependent variable. Without constants, two independent variables could change at the same time, and you would not know which variable affected the dependent variable.

Simple Beam Bridges

Before you read about the bridge-collapse investigation, think about the structure of bridges. The simplest type of bridge is a beam bridge, as shown in **Figure 8.** This type of bridge has one horizontal beam across two supports. A beam bridge often is constructed across small creeks. A disadvantage of beam bridges is that they tend to sag in the middle if they are too long.

Figure 8 Simple beam bridges span short distances, such as small creeks.

Figure 9 Truss bridges can span long distances and are strengthened by a series of interconnecting triangles called trusses. ▶

Truss Bridges

A truss bridge, shown in **Figure 9,** often spans long distances. This type of bridge is supported only at its two ends, but an assembly of interconnected triangles, or trusses, strengthens it. The I-35W bridge, shown in **Figure 10,** was a truss bridge designed in the early 1960s. The I-35W bridge was designed with straight beams connected to triangular and vertical supports. These supports held up the deck of the bridge, or the roadway. The beams in the bridge's deck and the supports came together at structures known as gusset plates, shown below on the right. These steel plates joined the triangular and vertical truss elements to the overhead roadway beams. These beams ran along the deck of the bridge. This area, where the truss structure connects to the roadway portion of the bridge at a gusset plate, also is called a node.

Reading Check What are the gusset plates of a bridge?

Figure 10 Trusses were a major structural element of the I-35W bridge. The gusset plates at each node in the bridge, shown on the right, are critical pieces that hold the bridge together. ▼

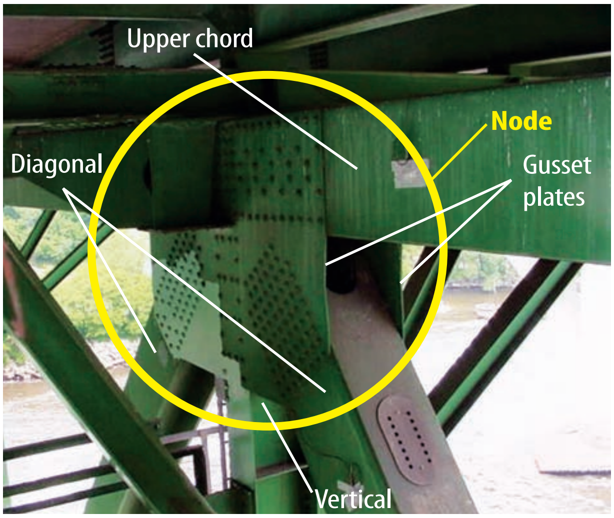


Figure 11 The collapsed bridge was further damaged by rescue workers trying to recover victims of the accident.

Bridge Failure Observations

After the I-35W bridge collapsed, shown in **Figure 11,** the local sheriff's department handled the initial recovery of the collapsed bridge structure. Finding, freeing, and identifying victims was a high priority, and unintentional damage to the collapsed bridge occurred in the process. However, investigators eventually recovered the entire structure.

The investigators labeled each part with the location where it was found. They also noted the date when they removed each piece. Investigators then moved the pieces to a nearby park. There, they placed the pieces in their relative original positions. Examining the reassembled structure, investigators found physical evidence they needed to determine where the breaks in each section occurred.

The investigators found more clues in a video. A motion-activated security camera recorded the bridge collapse. The video showed about 10 seconds of the collapse, which revealed the sequence of events that destroyed the bridge. Investigators used this video to help pinpoint where the collapse began.

Scientists often observe and gather information about an object or an event before proposing a hypothesis. This information is recorded or filed for the investigation.

Observations:
- Recovered parts of the collapsed bridge
- A video showing the sequence of events as the bridge fails and falls into the river

Asking Questions

One or more factors could have caused the bridge to fail. Was the original bridge design faulty? Were bridge maintenance and repair poor or lacking? Was there too much weight on the bridge at the time of the collapse? Each of these questions was studied to determine why the bridge collapsed. Did one or a combination of these factors cause the bridge to fail?

Asking questions and seeking answers to those questions is a way that scientists formulate hypotheses.

When gathering information or collecting data, scientists might perform an experiment, create a model, gather and evaluate evidence, or make calculations.

Qualitative data:
A thicker layer of concrete was added to the bridge to protect rods.

Quantitative data:
• The concrete increased the load on the bridge by 13.4 percent.

• The modifications in 1998 increased the load on the bridge by 6.1 percent.

• At the time of the collapse in 2007, the load on the bridge increased by another 20 percent.

Gathering Information and Data

Investigators reviewed the modifications made to the bridge since it opened in 1967. In 1977, engineers noticed that salt used to deice the bridge during winter weather was causing the reinforcement rods in the roadway to weaken. To protect the rods, engineers applied a thicker layer of concrete to the surface of the bridge roadway. Analysis after the collapse revealed that this extra concrete increased the dead load on the bridge by about 13.4 percent. A load can be a force applied to the structure from the structure itself (dead load) or from temporary loads such as traffic, wind gusts, or earthquakes (live load). Investigators recorded this qualitative and quantitative data. **Qualitative data** *uses words to describe what is observed.* **Quantitative data** *uses numbers to describe what is observed.*

In 1998, additional modifications were made to the bridge. The bridge that was built in the 1960s did not meet current safety standards. Analysis showed that the changes made to the bridge during this renovation further increased the dead load on the bridge by about 6.1 percent.

An Early Hypothesis

At the time of the collapse in 2007, the bridge was undergoing additional renovations. Four piles of sand, four piles of gravel, a water tanker filled with over 11,000 L of water, a cement tanker, a concrete mixer, and other equipment, supplies, and workers were assembled on the bridge. This caused the load on the bridge to increase by about 20 percent. In addition to these renovation materials, normal vehicle traffic was on the bridge. Did the renovation equipment and traffic overload the bridge, causing the center section to collapse as shown in **Figure 12?** Only a thorough analysis could answer this question.

A hypothesis is a possible explanation for an observation that can be tested by scientific investigations.

Hypothesis:
The bridge failed because it was overloaded.

Figure 12 The center section of the bridge broke away and fell into the river.

Figure 13 Engineers used computer models to study the structure and loads on the bridge.

Computer Modeling

The analysis of the bridge was conducted using computer-modeling software, as shown in **Figure 13.** Using computer software, investigators entered data from the Minnesota bridge into a computer. The computer performed numerous mathematical calculations. After thorough modeling and analysis, it was determined that the bridge was not overloaded.

Revising the Hypothesis

Evaluations conducted in 1999 and 2003 provided additional clues as to why the bridge failed. As part of the study, investigators took numerous pictures of the bridge structure. The photos revealed bowing of the gusset plates at the eleventh node from the south end of the bridge. Investigators labeled this node *U10*. Gusset plates are designed to be stronger than the structural parts they connect. It is possible that the bowing of the plates indicated a problem with the gusset plate design. Previous inspectors and engineers missed this warning sign.

The accident investigators found that some recovered gusset plates were fractured, while others were not damaged. If the bridge had been properly constructed, none of the plates should have failed. But inspection showed that some of the plates failed very early in the collapse.

After evaluating the evidence, the accident investigators formulated the hypothesis that the gusset plates failed, which lead to the bridge collapse. Now investigators had to test this hypothesis.

Hypothesis:
~~1. The bridge failed because it was overloaded.~~
2. The bridge collapsed because the gusset plates failed.
Prediction:
If a gusset plate is not properly designed, then a heavy load on a bridge will cause a gusset plate to fail.

Test the Hypothesis:
- Compare the load on the bridge when it collapsed with the load limits of the bridge at each of the main gusset plates.
- Determine the demand-to-capacity ratios for the main gusset plates.
- Calculate the appropriate thicknesses of the U10 gusset plates.

Independent Variables: actual load on bridge and load bridge was designed to handle

Dependent Variable: demand-to-capacity ratio

Testing the Hypothesis

The investigators knew the load limits of the bridge. To calculate the load on the bridge when it collapsed, they estimated the combined weight of the bridge and the traffic on the bridge. The investigators divided the load on the bridge when it collapsed by the load limits of the bridge to find the demand-to-capacity ratio. The demand-to-capacity ratio provides a measure of a structure's safety.

Analyzing Results

As investigators calculated the demand-to-capacity ratios for each of the main gusset plates, they found that the ratios were particularly high for the U10 node. The U10 plate, shown in **Figure 14,** failed earliest in the bridge collapse. **Table 4** shows the demand-to-capacity ratios for a few of the gusset plates at some nodes. A value greater than 1 means the structure is unsafe. Notice how high the ratios are for the U10 gusset plate compared to the other plates.

Further calculations showed that the U10 plates were not thick enough to support the loads they were supposed to handle. They were about half the thickness they should have been.

Key Concept Check Why are evaluation and testing important in the design process?

Figure 14 The steel plates, or gusset plates, at the U10 node were too thin for the loads the bridge carried.

Table 4 Node-Gusset Plate Analysis

Gusset Plate	Thick-ness (cm)	Demand-to-Capacity Ratios for the Upper-Node Gusset Plates					
		Horizontal loads			Vertical loads		
U8	3.5	0.05	0.03	0.07	0.31	0.46	0.20
U10	1.3	1.81	1.54	1.83	1.70	1.46	1.69
U12	2.5	0.11	0.11	0.10	0.71	0.37	1.15

Drawing Conclusions

Over the years, modifications to the I-35W bridge added more load to the bridge. On the day of the accident, traffic and the concentration of construction vehicles and materials added still more load. Investigators concluded that if the U10 gusset plates were properly designed, they would have supported the added load. When the investigators examined the original records for the bridge, they were unable to find any detailed gusset plate specifications. They could not determine whether undersized plates were used because of a mistaken calculation or some other error in the design process. The only thing that they could conclude with certainty was that undersized gusset plates could not reliably hold up the bridge.

The Federal Highway Administration and the National Transportation Safety Board published the results of their investigations. These published reports now provide scientists and engineers with valuable information they can use in future bridge designs. These reports are good examples of why it is important for scientists and engineers to publish their results and to share information.

Key Concept Check Give three examples of the scientific inquiry process that was used in this investigation.

Analyzing Results:
The U10 gusset plates should have been twice as thick as they were to support the bridge.

Conclusions:
The bridge failed because the gusset plates were not properly designed and they could not carry the load that they were supposed to carry.

Lesson 3 Review

Assessment Online Quiz

Use Vocabulary

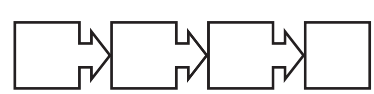
1. **Distinguish** between qualitative data and quantitative data.
2. **Contrast** *variable, independent variable,* and *dependent variable.*

Understand Key Concepts

3. Constants are necessary in a controlled experiment because, without constants, you would not know which variable affected the
   A. control group.
   B. experimental group.
   C. dependent variable.
   D. independent variable.
4. **Give an example** of a situation in your life in which you depend on adequate testing and evaluation in a product design to keep you safe.

Interpret Graphics

5. **Summarize** Copy and fill in the flow chart below and summarize the sequence of scientific inquiry steps that was used in one part of the case study.



Critical Thinking

6. **Analyze** how the scientific inquiry process differs when engineers design a product, such as a bridge, and when they investigate design failure.
7. **Evaluate** why the gusset plates were such a critical piece in the bridge design.
8. **Recommend** ways that bridge designers and inspectors can prevent future bridge collapses.

Build and Test a Bridge

Materials


plastic straws


ruler


scissors


cotton string


cardboard

Also needed: notebook paper, books or other masses, balance (with a capacity of at least 2 kg)

Safety

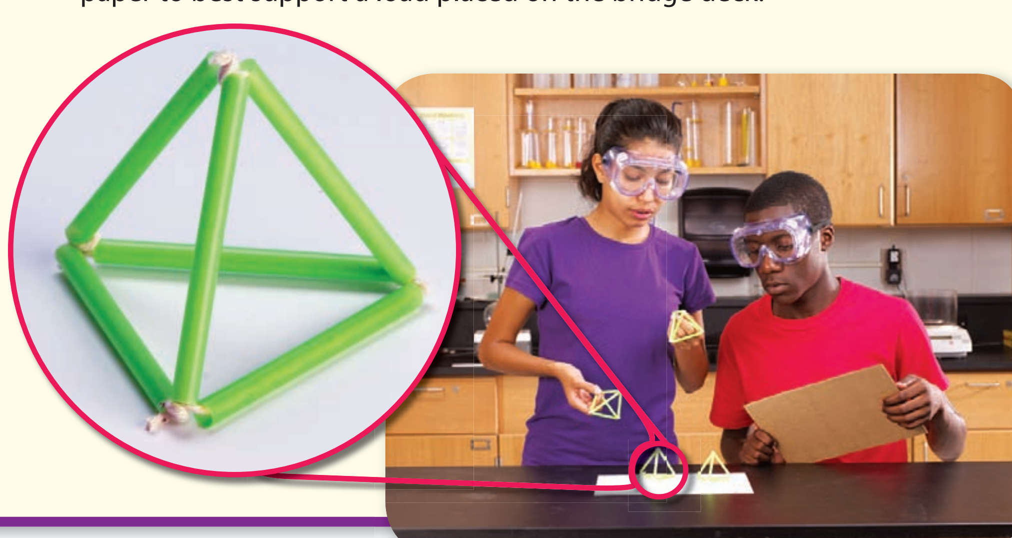
In the Skill lab, you observed the relative strengths of two different geometric shapes. In the case study about the bridge collapse, you learned how scientists used scientific inquiry to determine the cause of the bridge collapse. In this investigation, you will combine geometric shapes to build model bridge supports. Then you will use scientific inquiry to determine the maximum load that your bridge will hold.

Ask a Question

What placement of supports produces the strongest bridge?

Make Observations

1. Read and complete a lab safety form.
2. Cut the straws into 24 6-cm segments.
3. Thread three straw segments onto a 1-m piece of string. Slide the segments toward one end of the string. Double knot the string to form a triangle. There should be very little string showing between the segments.
4. Thread the long end of the remaining string through two more straw segments. Double knot the string to one unattached corner to form another triangle. Cut off the remaining string, leaving at least a 1 cm after the knot. Use the string and one more straw segment to form a tetrahedron, as shown below.
5. Use the remaining string and straw segments to build three more tetrahedrons.
6. Set the four tetrahedrons on a piece of paper. They will serve as supports for your bridge deck, a 20-cm x 30-cm piece of cardboard.
7. With your teammates, decide where you will place the tetrahedrons on the paper to best support a load placed on the bridge deck.



Form a Hypothesis

8. Form a hypothesis about where you will place your tetrahedrons and why that placement will support the most weight. Recall that a hypothesis is an explanation of an observation.

Test Your Hypothesis

9. Test your hypothesis by placing the tetrahedrons in your chosen locations on the paper. Lay the cardboard "bridge deck" over the top.
10. Use a balance to find the mass of a textbook. Record the mass in your Science Journal.
11. Gently place the textbook on the bridge deck. Continue to add massed objects until your bridge collapses. Record the total mass that collapsed the bridge.
12. Examine the deck and supports. Look for possible causes of bridge failure.

Analyze and Conclude

13. **Analyze** Was your hypothesis supported? How do you know?
14. **Compare and Contrast** Study the pictures of bridges in Lesson 3. How does the failure of your bridge compare to the failure of the I-35W bridge?
15. **The Big Idea** What steps of scientific inquiry did you use in this activity? What would you do next to figure out how to make a stronger bridge?

Communicate Your Results

Compare your results with those of several other teams. Discuss the placement of your supports and any other factors that may cause your bridge to fail.

Inquiry Extension

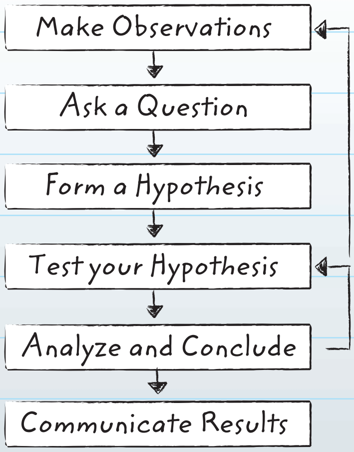
Try building your supports with straw segments that are shorter (4 cm long) and longer (8 cm long). Test your bridges in the same way with each size of support.

11

Lab Tips

- ☑ When building your tetrahedrons, make sure to double knot all connections and pull them tight. When you are finished, test each tetrahedron by pressing lightly on the top point.
- ☑ When adding the books to the bridge deck, place the books gently on top of the pile. Do not drop them.

Remember to use scientific methods.



Study Guide and Review

WebQuest

Scientific inquiry is a collection of methods that scientists use in different combinations to perform scientific investigations.

Key Concepts Summary

Lesson 1: Scientific Inquiry

- Some steps used during scientific inquiry are making **observations** and **inferences,** developing a **hypothesis,** analyzing results, and drawing conclusions. These steps, among others, can be performed in any order.
- There are many results of scientific inquiry, and a few possible outcomes are the development of new materials and new technology, the discovery of new objects and events, and answers to basic questions.
- **Critical thinking** is comparing what you already know about something to new information and deciding whether or not you agree with the new information.

Vocabulary

science p. NOS 4
observation p. NOS 6
inference p. NOS 6
hypothesis p. NOS 6
prediction p. NOS 6
scientific theory p. NOS 8
scientific law p. NOS 8
technology p. NOS 9
critical thinking p. NOS 10

Lesson 2: Measurement and Scientific Tools

- Scientists developed one universal system of units, the **International System of Units (SI),** to improve communication among scientists.
- **Scientific notation** is a useful tool for writing large and small numbers in a shorter form.
- Tools such as graduated cylinders and triple-beam balances make scientific investigation easier, more accurate, and repeatable.

Vocabulary

description p. NOS 12
explanation p. NOS 12
International System of Units (SI) p. NOS 12
scientific notation p. NOS 15
percent error p. NOS 15

Lesson 3: Case Study—The Minneapolis Bridge Failure

- Evaluation and testing are important in the design process for the safety of the consumer and to keep costs of building or manufacturing the product at a reasonable level.
- Scientific inquiry was used throughout the process of determining why the bridge collapsed, including hypothesizing potential reasons for the bridge failure and testing those hypotheses.

Vocabulary

variable p. NOS 21
independent variable p. NOS 21
dependent variable p. NOS 21
constants p. NOS 21
qualitative data p. NOS 21
quantitative data p. NOS 21
experimental group p. NOS 24
control group p. NOS 24

Use Vocabulary

1. The ________ contains the same factors as the experimental group, but the independent variable is not changed.
2. The expression of error as a percentage of the accepted value is ________.
3. The process of studying nature at all levels and the collection of information that is accumulated is ________.
4. The ________ are the factors in the experiment that stay the same.

Assessment
Online Test Practice

Understand Key Concepts

5 Which is NOT an SI base unit?

A. kilogram
B. liter
C. meter
D. second

6 While analyzing results from an investigation, a scientist calculates a very small number that he or she wants to make easier to use. Which does the scientist use to record the number?

A. explanation
B. inference
C. scientific notation
D. scientific theory

7 Which is NOT true of a scientific law?

A. It can be modified or rejected.
B. It states that an event will occur.
C. It explains why an event will occur.
D. It is based on repeated observations.

8 Which tool would a scientist use to find the mass of a small steel rod?

A. balance
B. computer
C. hot plate
D. thermometer

Critical Thinking

9 **Write** a brief description of the activity shown in the photo.

Writing in Science

10 **Write** a five-sentence paragraph that gives examples of how critical thinking, skepticism, and identifying facts and opinions can help you in your everyday life. Be sure to include a topic sentence and concluding sentence in your paragraph.

REVIEW THE BIG IDEA

11 What is scientific inquiry? Explain why it is a constantly changing process.

12 Which part of scientific inquiry does this photo demonstrate?

Math Skills

Review
Math Practice

13 The accepted scientific value for the density of sucrose is 1.59 g/cm^3. You perform three trials to measure the density of sucrose, and your data is shown in the table below. Calculate the percent error for each trial.

Trial	Density	Percent Error
Trial 1	1.55 g/cm^3	
Trial 2	1.60 g/cm^3	
Trial 3	1.58 g/cm^3	